COIL WINDING TENSION AS IT APPLIES
TO WIRE SPRING RELAY COILS
AND OTHER FILLED TYPE COILS

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INTRODUCTION AND PURPOSE

Since the 1930's, when the filled coil winding machine was developed to wind two or more coils at a time on an arbor instead of individually on spools, the filled coil has been used by Western Electric for most switch and relay coils. During these years the tension with which the wire was wound on the coil depended largely on what the winding operator considered best for winding a smooth and uniform stick of coils. Usually, she did not know the actual amount of the tension. Checks were made during machine setup, and at other convenient times when the machine was stopped, by pulling wire through the wire guide with a barrel-type gage at about walking speed. Sometimes wire was pulled by hand, in which case the tension was judged by feel. When difficulty was encountered with such things as wire breakage, high resistance, or wire falling off the end of the coil, a commercial gage was sometimes used. Its use was limited in the case of the rubber wheel type wire tensioner, which is considered standard equipment, because of the time the machine had to be stopped while the gage was being mounted on the wire guide prior to making the reading and while it was removed afterward. Even then it was not certain what tension value should be used, although a table of values published in the manual for the machine, and in layouts, served as a guide.

Recently, a pulley wheel attachment, C-653963, was developed by this writer for use on the tension end of a barrel-type tension gage. This attachment, when used between two wheels on the rubber wheel-type wire tensioner on the winding machine, forms a three-wheel tension gage. The wheel is placed back of the wire in the wire guide as the coil is being wound and then pulled forward 5-6" until the wires are nearly parallel (See Figure 1). The readings are twice the actual wire tension, but this is overcome by using tables of double values. After the reading and any necessary tension adjustments have been made, the wire is returned to its position in the wire guide and the next wire is checked. This is all done while the machine is running at full speed. The tensions of all the wires on a coil stick can be measured and corrections made by the operator in about one minute.

The ease and speed with which the tension can be determined and adjustments made, using the new method, has encouraged studies to be made which heretofore would not have been undertaken. Studies made thus far at Omaha have brought to light some interesting and important facts concerning tension and its effect on filled coil winding and assembly operations. It is the purpose of this paper to summarize the information accumulated regarding tension and its effect on wire spring relay coils, and to pass it on to fellow engineers and shop personnel who are interested in filled coil winding and assembly operations.

HOW THE STUDIES WERE CONDUCTED

Coil codes selected for the studies were full size coils wound with as wide a range of wire gages as scheduled coil codes permitted. In some cases more than one coil code using the same wire gage was studied to provide a check on the data and to permit comparisons to be made.

At the start of a test run of any selected coil code, the winding machine was loaded with full spools of wire to avoid a shift in data because of the introduction of a different spool of wire. Also, it was observed that there was enough interleaving paper on the roll for the run. This latter precaution was taken after it was observed during one of the early runs that the first few sticks of coils run after a roll change had a distinct shift to larger coils and higher resistance at the same tension.

The tensions were set while coils were being wound on one arbor, and the test coils were run on the second arbor to avoid any irregularities due to the use of different arbors. In some cases the tensions were checked and fine adjustments made during the winding of the test coil stick. The tensions used started at 50 grams (100 grams on the gage) and progressed upward in convenient steps until difficulty was encountered with such things as wire breakage or the coil sticks being too difficult to remove from the arbor.

As the coils were being wound, close attention was given to winding problems that might be the result of not enough or too much tension. It was found, for instance, that if the tension was much below 50 grams the coil stick would sometimes slip on the arbor when the cover paper was applied, and occasionally the core insulation would stay on the arbor when the coil stick was pulled from the arbor. At the higher tensions there was excessive wire breakage for fine wire coils, wire fell out in space, and the coil stick was difficult to remove from the arbor.

Each coil was marked with the number of the coil on the stick and the tension used. Diameter measurements were made to the nearest 1/1000 inch with a dial vernier caliper placed over the outer tape and near the center of the coil.

After the coils were flattened and cut, they were measured as before for coil thickness. Some coils wound at low tension values were found to be too large to permit them to be flattened enough to meet the maximum thickness tolerance. Visual examination of the coils revealed that for high tension values there were frequent cases where the core insulator collapsed, making it difficult, if not impossible, to proceed with the coalescing operation. Each coil was checked for resistance using a bridge which automatically corrected for room temperature and read directly in per cent deviation from the specified nominal resistance. In some cases the coils were held for a period of time and then remeasured for flatness to determine whether they "spring back." Because of the irregularities in the coil cover and in the outer layer of wire, it was to be expected that there would be small variations in repeated readings; therefore, average values were used. No significant correlation between tension and "spring back" was noted, but an average "spring back" of about .003" did seem to occur.

The test coils were coalesced in the normal manner. Some coils were checked for thickness before and after coalescing to determine whether the coalescing operation caused the coils to "spring back." The results were negative. The coalesced coils were tried on cores to determine what effect tension had in this respect. Those wound with low or medium tensions slipped on the core easily, but some of those wound with high tension values offered resistance to the extent that the core insulator might have been pushed out, or the coil actually could not be assembled on the core.

SOURCES OF WINDING TENSION AND TENSIONING DEVICES

The tension on the wire as it is wound on the coil is the summation of all the tensioning forces applied to the wire from the supply spool to the coil. It includes the force required to overcome the inertia of the wire in getting it started in motion. It includes the friction on the wire as it passes over the rim of the spool, through eyelets and between wire guiding plates, and the friction of the bearings of any wheels the wire may pass over. It includes, of course, the tension applied by a special tensioning device which automatically applies an adjustable amount of tension to the wire. Fortunately, the other tensions applied to the wire are small and fairly stable under normal conditions so that the total tension can be controlled by this tensioning device.

A number of different types of tensioning devices have been or are being used. If the supply spool turns to dereel the wire, it is necessary to use some type of brake to stop the spool from turning when the machine stops. An arm connected to this brake and actuated by the wire in such a way as to reduce the drag when the tension increases, provides an automatic tensioning device. Adjustment is made by changing the tension of the spring holding the brake shoe against the brake drum, and/or by changing the length of the arm or mechanical linkages actuating the brake.

The capstan-type tensioner, as with the remaining types that will be mentioned here, is suitable for use when the wire is dereeled over the end of a stationary spool, or from a container. Wire from the supply is usually wrapped around the capstan wheel to prevent slippage. A friction-type brake is applied to the capstan wheel by a spring which can be adjusted to provide the tension desired. This type has had only limited use.

The standard tensioner for the filled coil winding machine, and the one on which this report is based, has a wheel with a rubber tire wedged between two smooth hard surfaced wheels by an adjusting screw. The wire, in passing between these wheels, must cause them to turn against the drag produced by the rubber tire. The tighter the wheels are held against each other, the higher the tension. The tension remains almost constant over the speed range normally used for winding coils.

A commercial hysteresis-type tensioner used at some Company locations is similar to the capstan-type, except that instead of using mechanical friction for the braking force, a small hysteresis generator is used. Adjustment is made by changing the electro-magnetic characteristics. The tension rises only slightly as the winding speed increases.

A new type tensioner being studied at another Company location makes use of nylon cord twisted together tightly as in a rope. The wire passes through the center of this twist and is retarded by a force which is controlled by how tightly the cords are twisted. This tensioner has the advantage of having no moving parts and no inertia, but has other disadvantages that limit its usefulness.

ABOUT COPPER WIRE, ITS GRADES AND SIZES

To understand more clearly the way copper wire responds to tension, it may be helpful to review some of the characteristics of the material and its sizes. Copper wire is made from highly refined copper. The metal is first cast into long bars which are later preheated and hot rolled into rods 1/4" in diameter. These rods are then cold-drawn through a series of wire dies which progressively reduce the size to form the gage of wire desired. The working of the wire as it is drawn through the dies hardens it and increases its tensile strength. The wire can be annealed by heating, and thus, be restored to its original soft state. This fact is the basis for the three commercial grades of wire as follows:

Hard-drawn copper wire is drawn through dies from rod to finished product without intermediate annealing, except for very fine wire. It has high strength and low elongation. (Minimum tensile strength is 67,000 psi.)

Medium-hard-drawn copper wire is a special product. It is annealed copper wire drawn down to a slightly smaller diameter. (Tensile strength

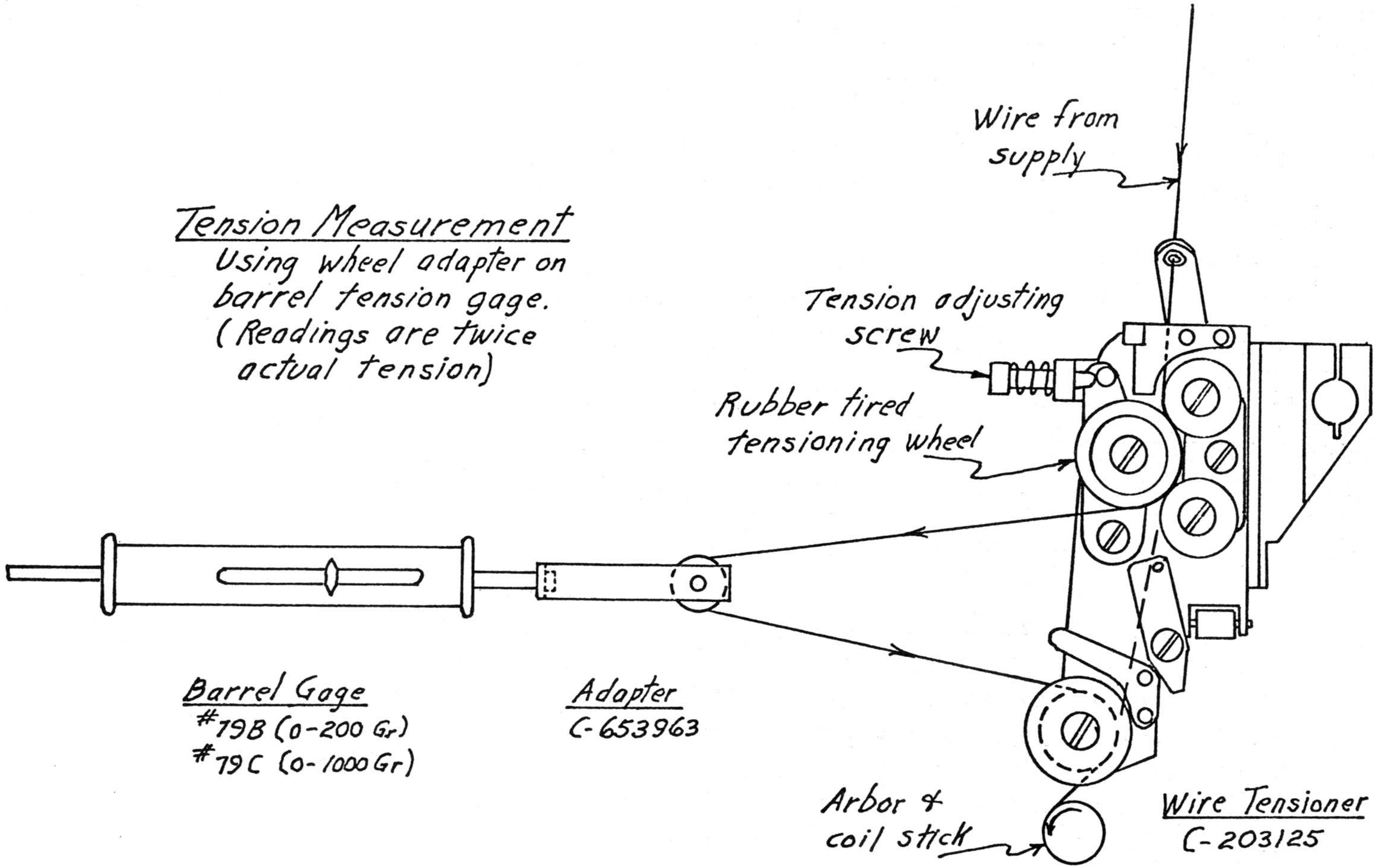

Wire from supply
Tension Measurement
Using wheel adapter on barrel tension gage. (Readings are twice actual tension)
Tension adjusting screw
Rubber tired tensioning wheel
Barrel Gage
#79B (0-200 Gr)
#79C (0-1000 Gr)
Adapter
C-653963
Arbor & coil stick
Wire Tensioner
C-203125

Figure 1

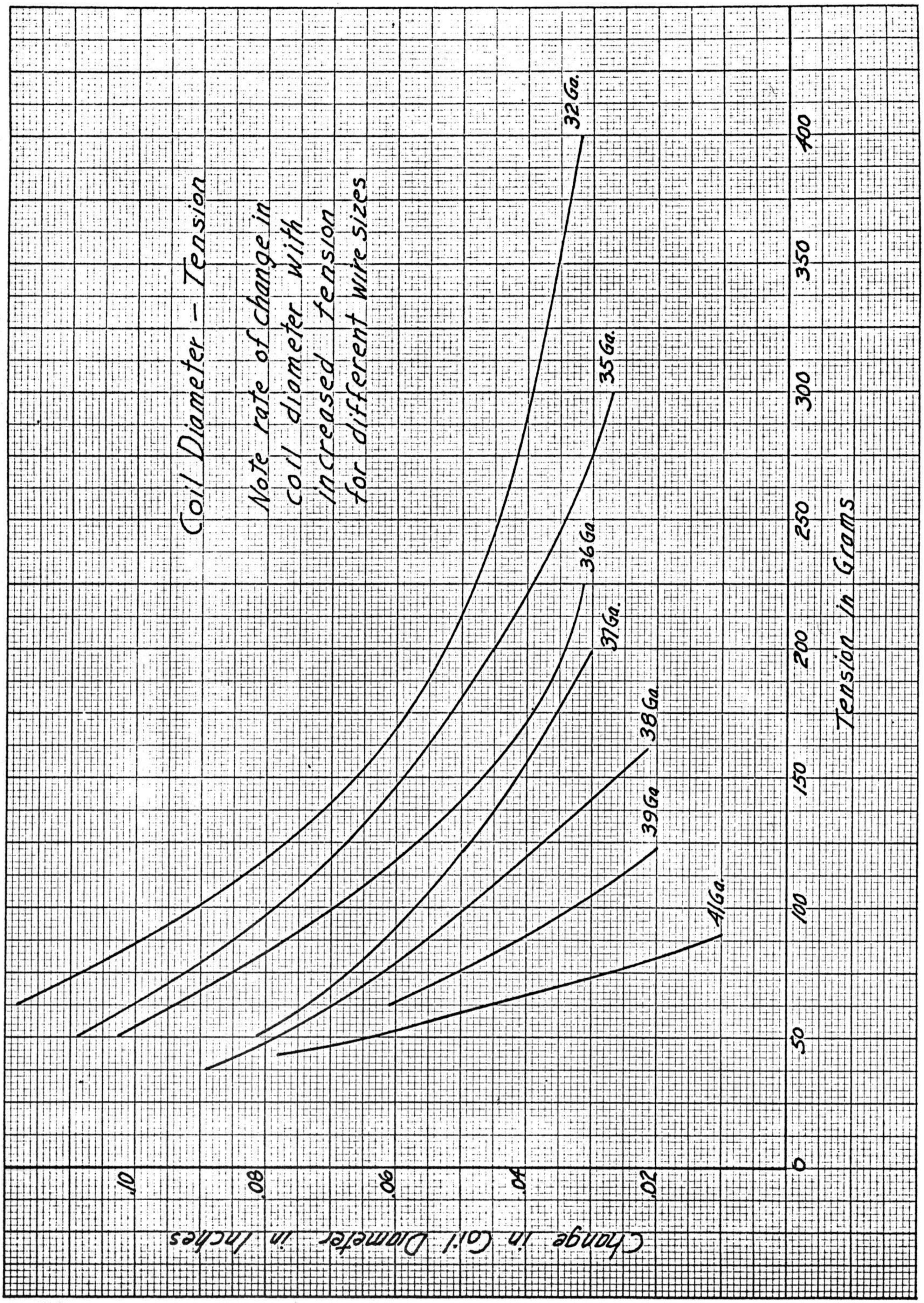

Coil Diameter - Tension
Note rate of change in
coil diameter with
increased tension
for different wire sizes
32 Ga.
35 Ga.
36 Ga
37 Ga.
38 Ga
39 Ga
41 Ga.
0
50
100
150
200
250
300
350
400
Tension in Grams
.10
.08
.06
.04
.02
Change in Coil Diameter in Inches

Figure 2

is between 53,000 and 60,000 psi.)

Soft or annealed copper wire is drawn and annealed. It is very soft and ductile and, therefore, is easily marred and stretched. (Maximum tensile strength is 38,500 psi.)

The wire used in switch and relay coils is soft or annealed copper wire. It has no definite elastic limit. It stretches slowly but permanently under relatively moderate stress, but in so doing, it hardens and tends to increase its own elastic limit.

The size of wire is designated by American Wire Gage (AWG) numbers 1 to 50 or more - the smaller the number, the larger the wire. Wires larger than No. 1 gage are designated as gages 0, 00, 000, and 0000, and beyond that, they are usually identified by their cross-sectional area in circular mils.

Wire size No. 0000 is exactly 0.4600" in diameter, and No. 36 gage is exactly 0.0050" in diameter. These two sizes form the basis for the other sizes developed mathematically by geometrical progression. The diameter of each larger gage is 1.123 times the diameter of the previous gage and the cross-sectional area of wire, and all related values such as weight per foot, strength, resistance per foot, etc., change by a factor of $(1.123)^2$ or 1.261.

THE EFFECT OF TENSION ON COIL SIZE

When coils are wound without interleaving paper, as in the case of spool-wound coils, the turns of wire fit themselves in the spaces and grooves between the turns of wire in the previous layer. This is true except for twice each turn when the wire must cross a lower turn because it is traversing the coil in the opposite direction. The tension required is small because it is only necessary for the wire to "find" the deepest part of the groove or space between two turns of the previous layer.

In the case of filled coils, in which a layer of interleaving insulating paper (cellulose acetate) separates each layer of wire, the diameter of the coil having a given number of turns of a certain gage of wire can be reduced by using more winding tension. If a very low tension is used, each interleaving paper will support the force exerted on it by the outer turns of wire with the result that the coil diameter will be at a maximum value. As the tension is increased, the interleaving paper will be forced more and more into the grooves between the wires of the previous layers of wire and a smaller coil will result.

The curves on Figure 2 show how the diameter of coils using different gages of wire decreased with increased winding tension. It will be noted that the lines for fine wires at low tension values are nearly straight, whereas those for the larger wires at high tension values progressively flatten out. This is because there is a limit to how much smaller a coil can be wound by increasing the winding tension. Once the interleaving paper is forced all the way in the groove, no further reduction in size can be had without deforming the cellulose acetate material or stretching the wire. In the latter case, as will be shown later, the resistance can be expected to increase.

COIL RESISTANCE - WHAT DETERMINES IT

There are three basic factors that determine the resistance of a coil: (1) the length of wire used to wind on the specified number of turns, (2) the cross-sectional area or gage of the wire, and (3) the resistivity of the wire material. The resistance is directly proportional to the length of the wire and inversely proportional to the cross-sectional area. For copper wire, the resistivity increases at a definite rate with increased temperature, but resistance limits are specified at 68° F and resistance measurements are usually corrected to this temperature.

For any given coil design in which a definite number of turns of a certain gage of wire is specified, the resistance will vary directly with the length of wire used. The smaller the coil is wound, of course, the shorter the length of wire and the lower the resistance; but if in using more tension to wind the coil smaller, the wire is stretched, the resistance can be expected to increase. This is due to the resistance going up much faster with reduction of wire diameter as the result of stretching than the coil getting smaller because of the smaller wire diameter. The former varies inversely with the square of the diameter change, while the latter varies only with the wire diameter change.

THE EFFECT OF TENSION ON RESISTANCE

For low tension values, the reduction of resistance by increased tension is directly related to the reduction in coil size. Through the choice of convenient scales, this can be seen on Figures 3 through 12 where coil diameter and resistance deviation are plotted against tension. Notice that the resistance deviation curve follows the coil diameter curve down until the tension reaches a certain value. It is here that the winding tension approaches the yield point of the wire, and it can be expected that some of the wire will be stretched so that its cross-sectional area is reduced and its resistance increased.

It must be realized that tension is not a constant value even with the best tensioning device. Each time the winding machine reverses to start a new layer, the wire is jerked slightly because the speed of the tensioning wheels must be increased suddenly to supply wire fast enough for the larger coil diameter. Rough spots on the supply spool flange and irregularities in the spooling of the wire will cause "tugs" on the wire which momentarily increase the total tension. Also, some segments of the wire will stretch with less tension than others.

The value at which the wire starts to stretch can be seen on the curves as the point where the resistance curve starts to decrease less rapidly than the coil diameter curve. This deviation increases quite rapidly as

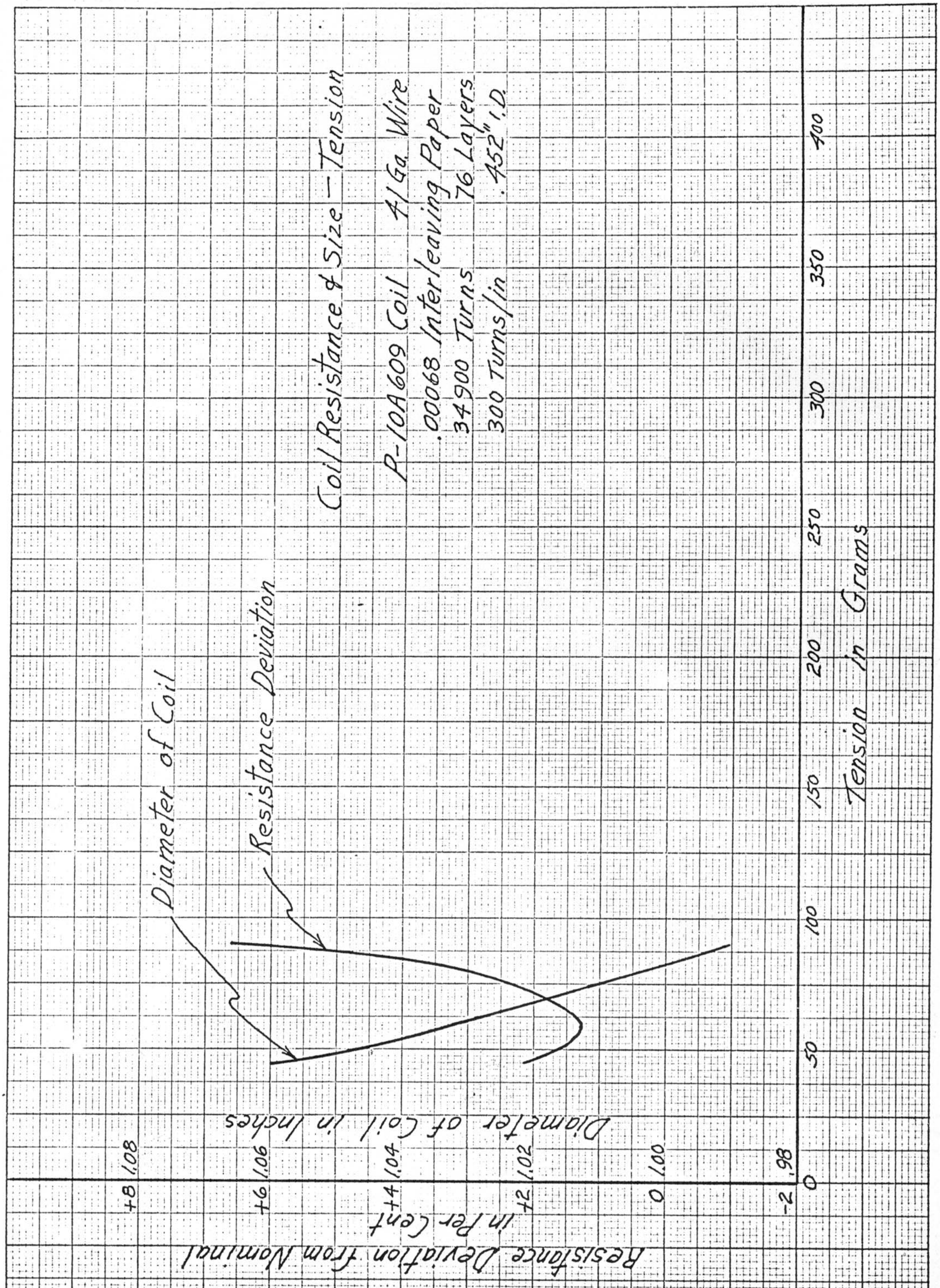

Coil Resistance & Size — Tension
P-10A609 Coil 41 Ga. Wire
.00068 Interleaving Paper
34900 Turns 76 Layers
300 Turns/in .452" I.D.
Diameter of Coil
Resistance Deviation
Tension in Grams
0 50 100 150 200 250 300 350 400
Diameter of Coil in Inches
.98 1.00 1.02 1.04 1.06 1.08
Resistance Deviation from Nominal in Per Cent
-2 0 +2 +4 +6 +8

Figure 3

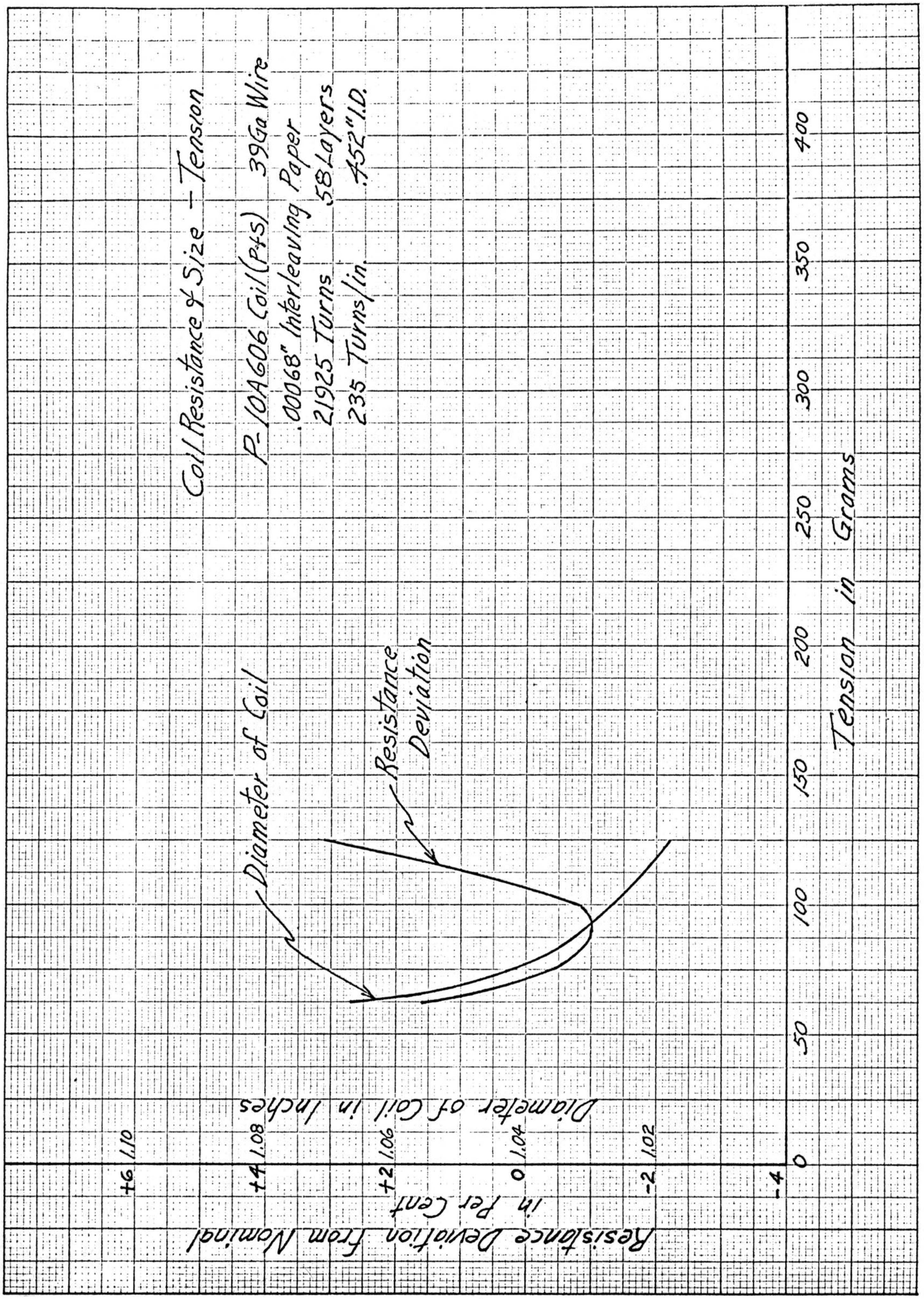

Coil Resistance & Size - Tension
P-10A606 Coil (P+S) 39Ga Wire
.00068" Interleaving Paper
21925 Turns 58 Layers
235 Turns/in. .452" I.D.
Diameter of Coil
Resistance Deviation
Tension in Grams
0 50 100 150 200 250 300 350 400
Diameter of Coil in Inches
1.02 1.04 1.06 1.08 1.10
Resistance Deviation from Nominal in Per Cent
-4 -2 0 +2 +4 +6

Figure 4

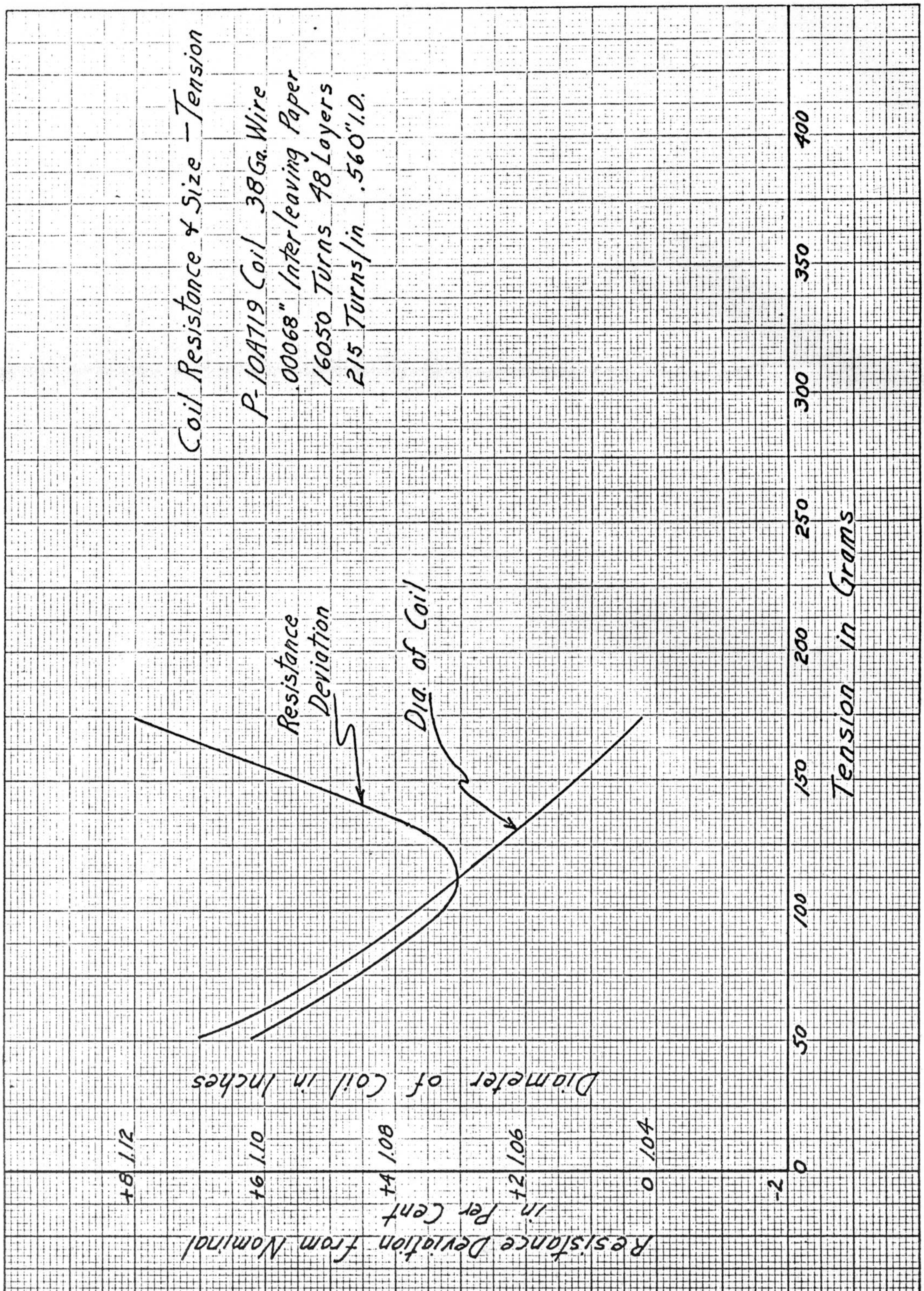

Coil Resistance & Size - Tension
P-10A719 Coil 38 Ga. Wire
.00068" Interleaving Paper
16050 Turns 48 Layers
215 Turns/in .560" I.D.
Resistance Deviation
Dia. of Coil
Diameter of Coil in Inches
Resistance Deviation from Nominal in Per Cent
Tension in Grams
+8 1.12
+6 1.10
+4 1.08
+2 1.06
0 1.04
-2
0
50
100
150
200
250
300
350
400

Figure 5

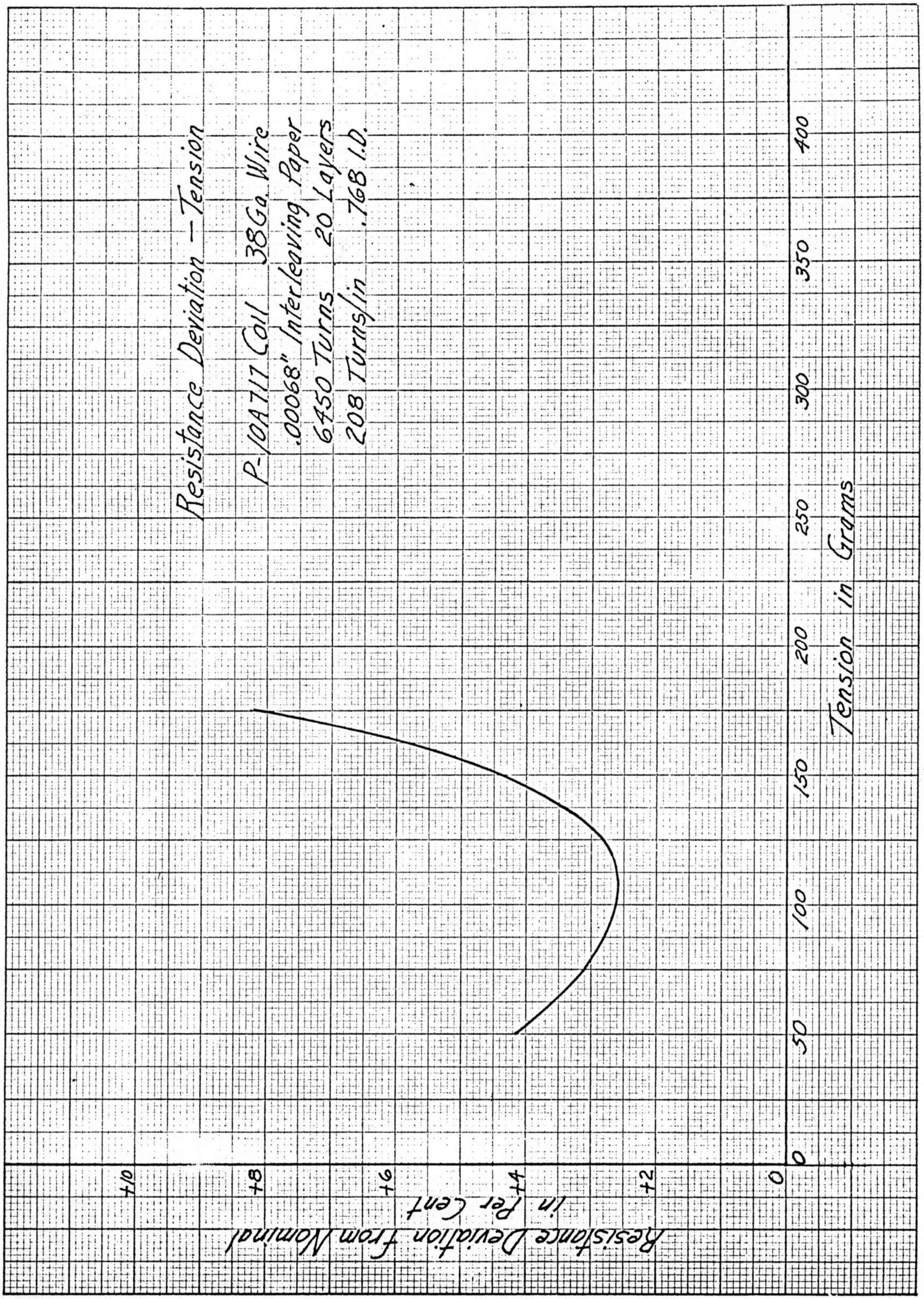
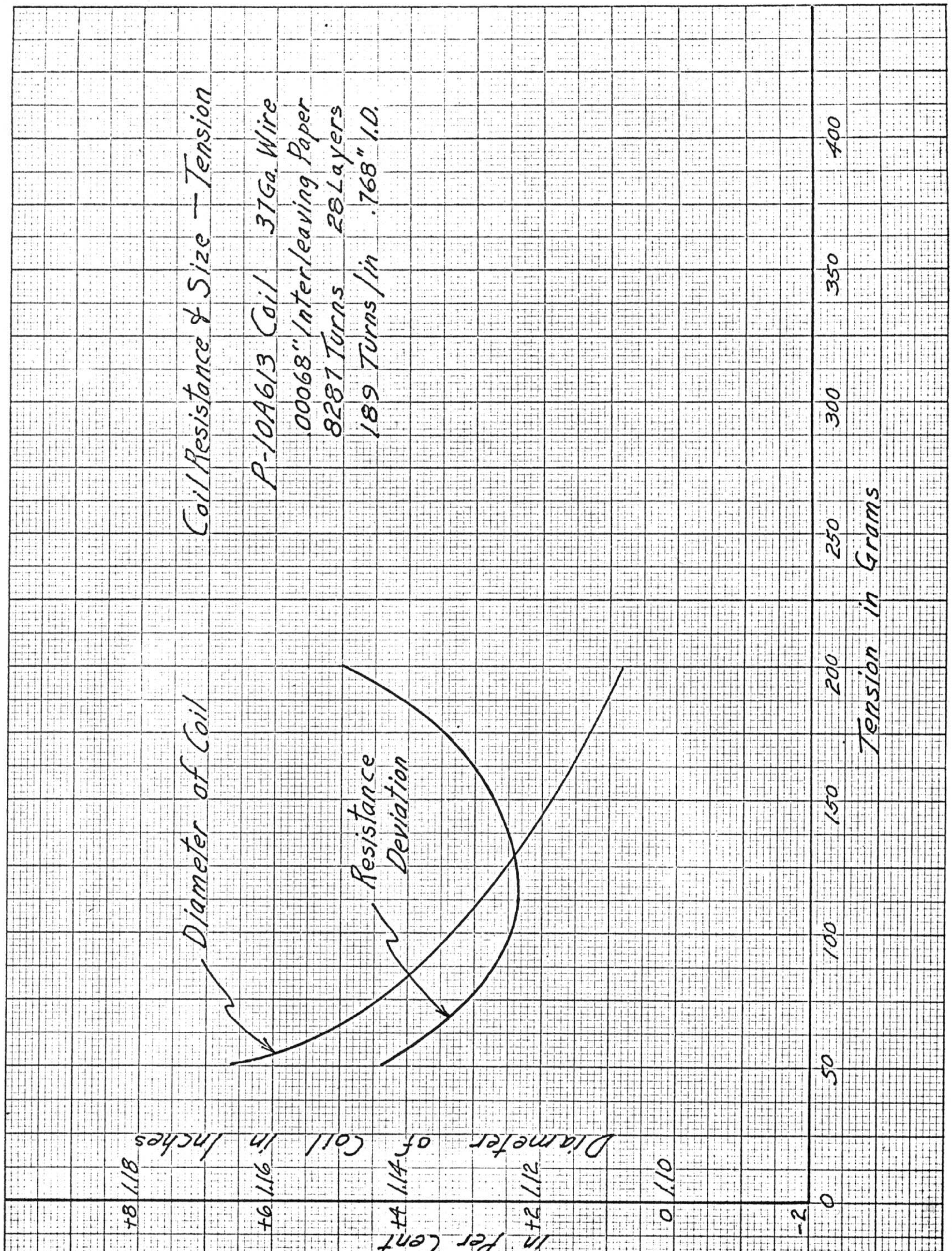


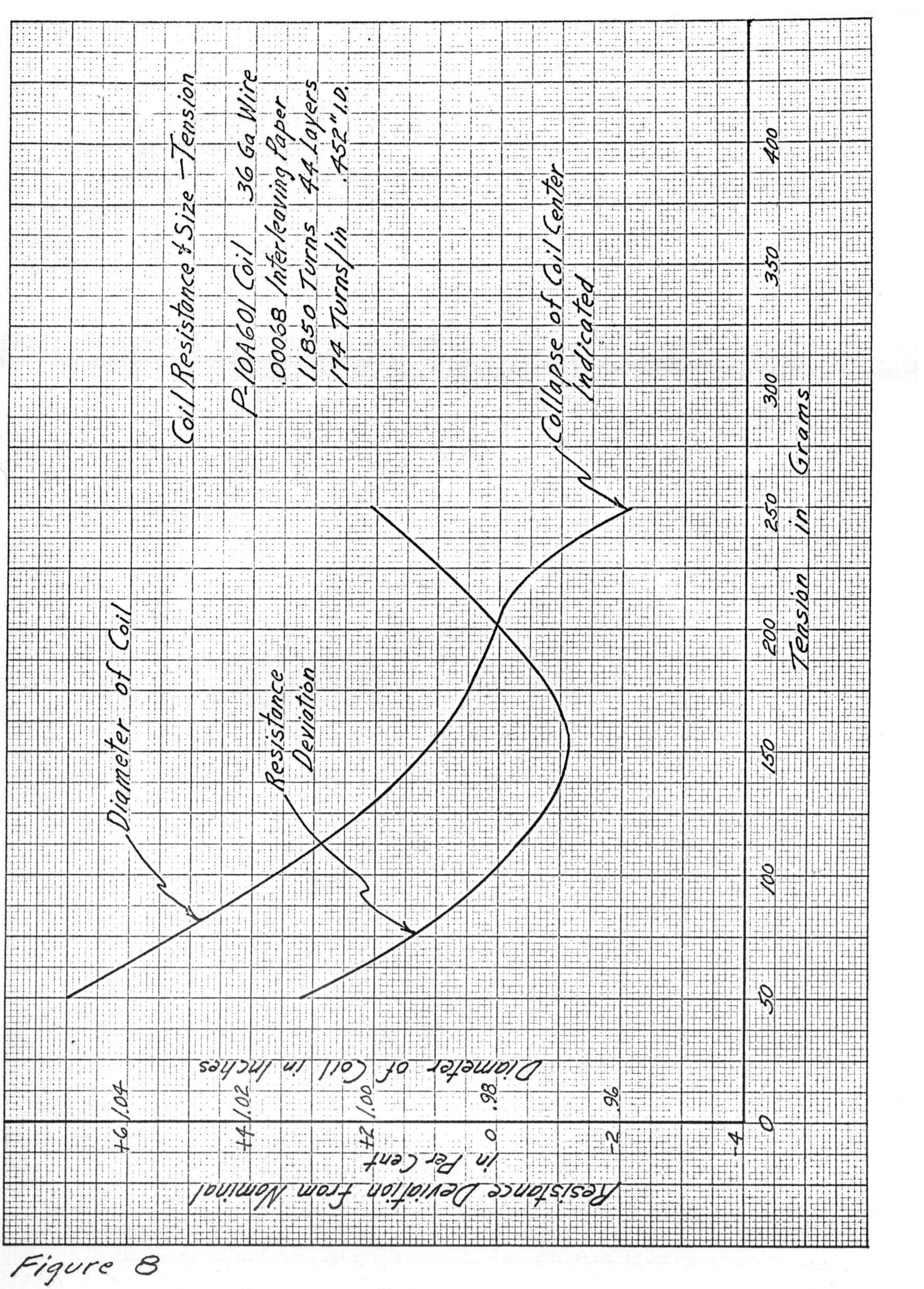
Figure 6

Figure 6



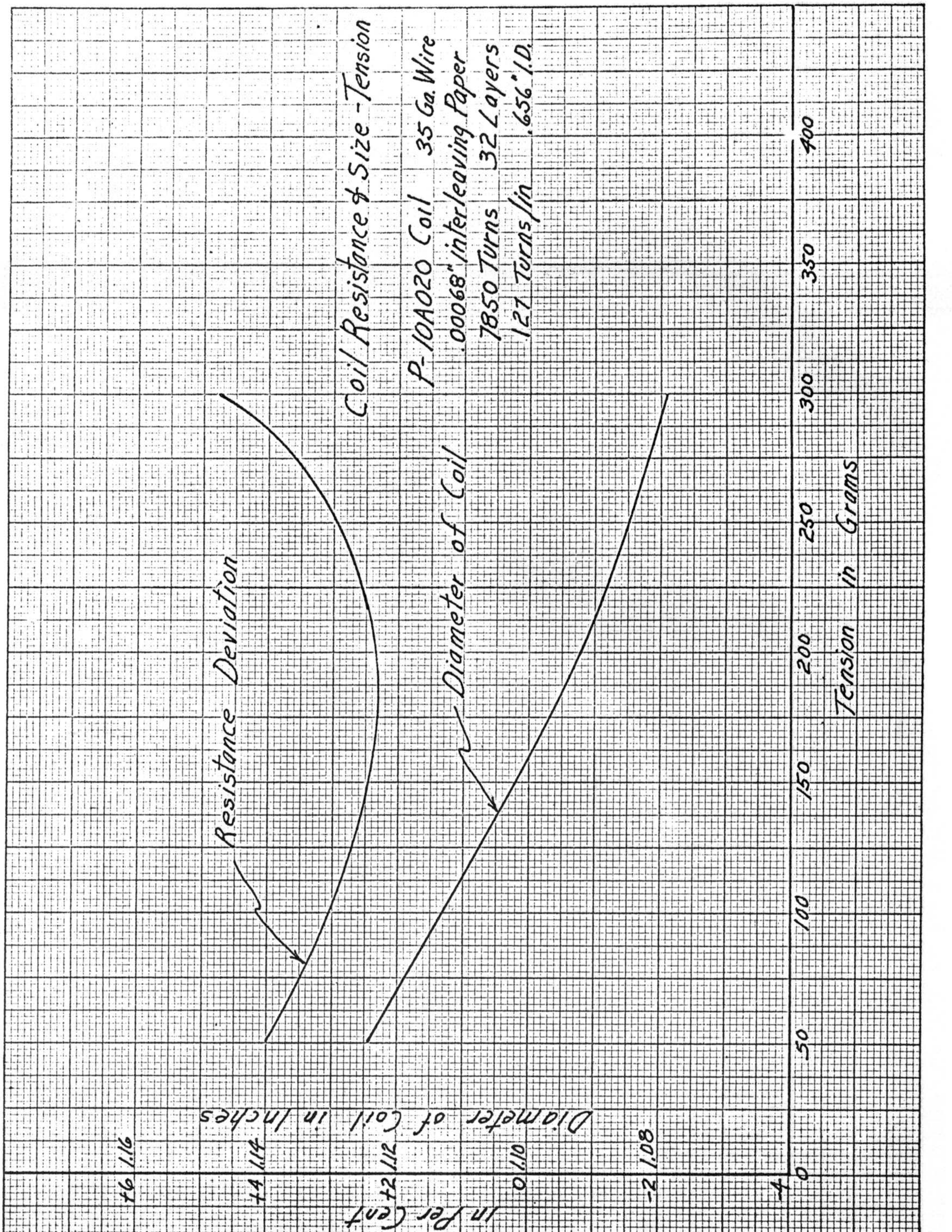
Coil Resistance & Size — Tension
P-10A613 Coil 37Ga. Wire
.00068" Interleaving Paper
8281 Turns 28 Layers
189 Turns/in .768" I.D.
Diameter of Coil
Resistance Deviation
Tension in Grams
0
50
100
150
200
250
300
350
400
Diameter of Coil in Inches
1.18
1.16
1.14
1.12
1.10
Resistance Deviation from Nominal in Per Cent
+8
+6
+4
+2
0
-2

Figure-7



Coil Resistance & Size — Tension
P-10A601 Coil 36 Ga Wire
.00068 Interleaving Paper
11850 Turns 44 Layers
174 Turns/in .452" I.D.
Collapse of Coil Center Indicated
Diameter of Coil
Resistance Deviation
Tension in Grams
0
50
100
150
200
250
300
350
400
Diameter of Coil in Inches
1.04
1.02
1.00
.98
.96
Resistance Deviation from Nominal in Per Cent
+6
+4
+2
0
-2
-4

 Figure 8



Coil Resistance & Size - Tension
P-10A020 Coil 35 Ga. Wire
.00068" interleaving Paper
7850 Turns 32 Layers
127 Turns/in .656" I.D.
Resistance Deviation
Diameter of Coil
Tension in Grams
0
50
100
150
200
250
300
350
400
Resistance Deviation from Nominal in Per Cent
+6
+4
+2
0
-2
-4
Diameter of Coil in Inches
1.16
1.14
1.12
1.10
1.08

Figure-9

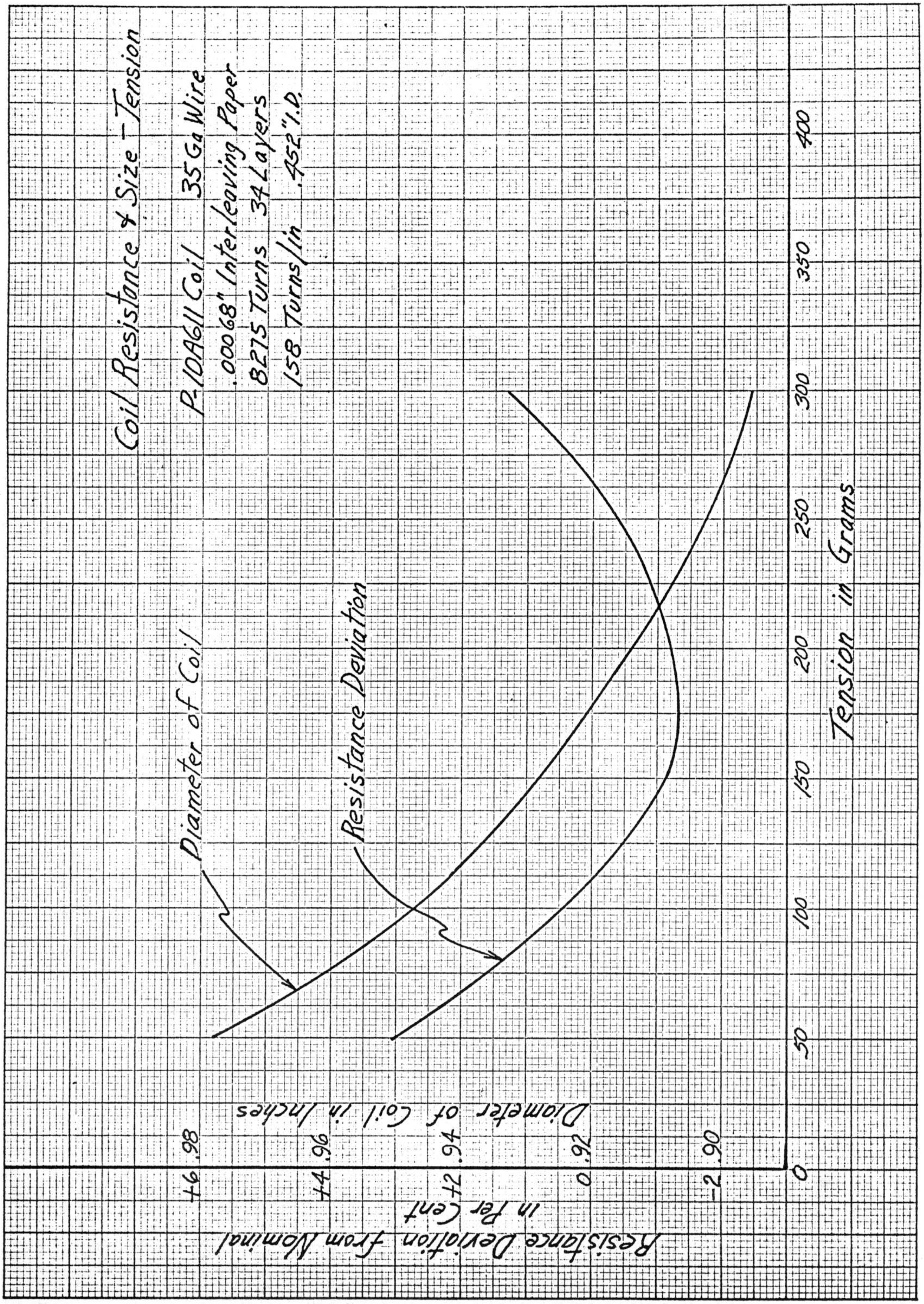
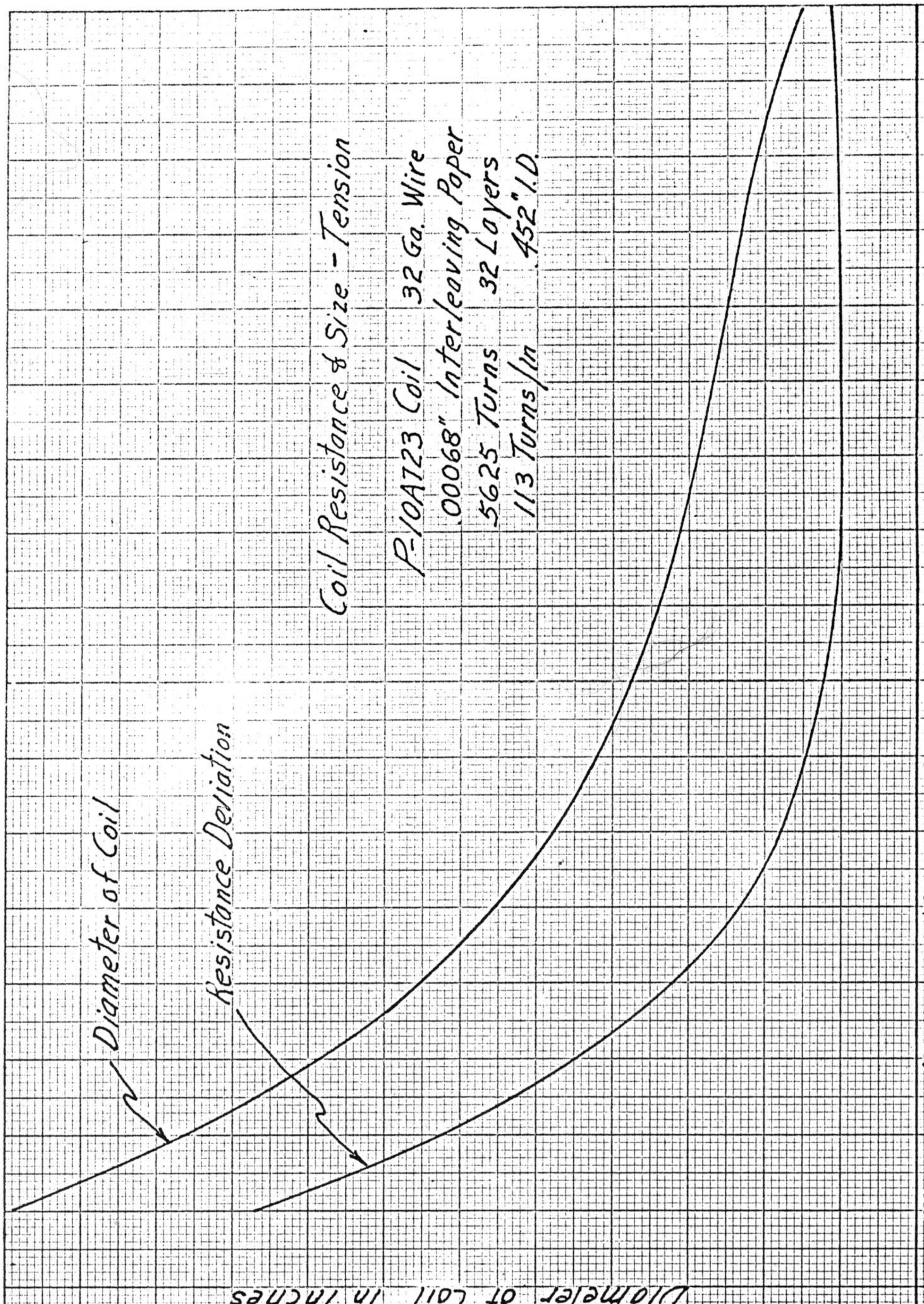

Coil Resistance & Size - Tension
P-1DA611 Coil 35 Ga Wire
.00068" Interleaving Paper
8275 Turns 34 Layers
158 Turns/in .452" I.D.
Diameter of Coil
Resistance Deviation
Diameter of Coil in Inches
.98
.96
.94
.92
.90
Resistance Deviation from Nominal in Per Cent
+6
+4
+2
0
-2
0
50
100
150
200
250
300
350
400
Tension in Grams

Figure 10



Coil Resistance & Size - Tension
P-10A723 Coil 32 Ga. Wire
.00068" Interleaving Paper
5625 Turns 32 Layers
113 Turns/In .452" I.D.
Diameter of Coil
Resistance Deviation
Tension in Grams
0
50
100
150
200
250
300
350
400
Diameter of Coil in Inches
1.12
1.10
1.08
1.06
1.04
Resistance Deviation from Nominal in Per Cent
+16
+14
+12
+10
+8
+6

Figure 11

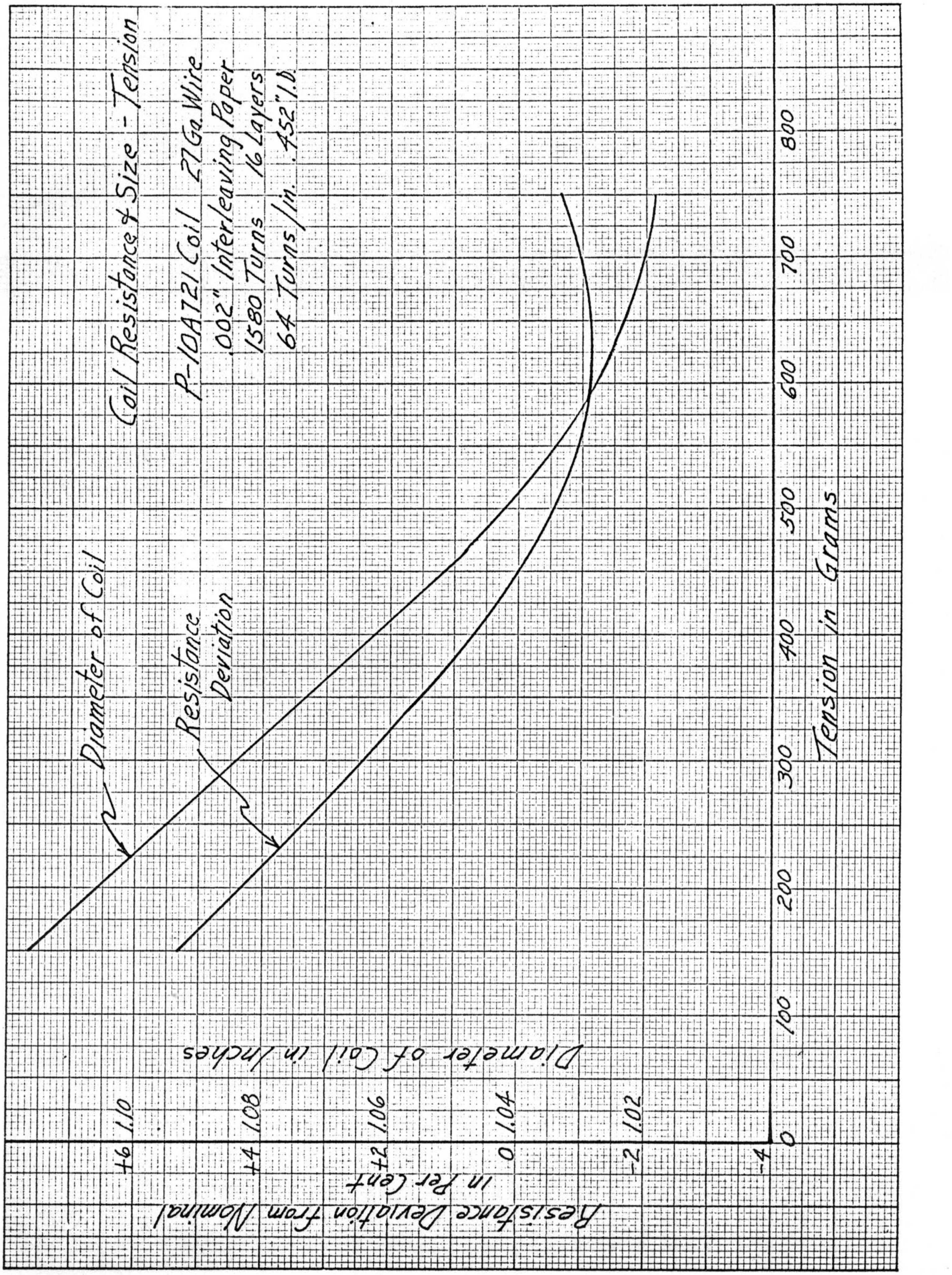

Coil Resistance & Size - Tension
P-10A721 Coil 27 Ga. Wire
.002" Interleaving Paper
1580 Turns 16 Layers
64 Turns/in. .452" I.D.
Diameter of Coil
Resistance Deviation
Tension in Grams
0
100
200
300
400
500
600
700
800
Diameter of Coil in Inches
1.10
1.08
1.06
1.04
1.02
Resistance Deviation from Nominal in Per Cent
+6
+4
+2
0
-2
-4

Figure 12

tension is increased until the resistance curve reaches a minimum value and starts to increase, even though the coil size may still be decreasing. This is the point where the resistance reducing effect of the coil being wound smaller is just equal to the resistance increasing effect of the wire being stretched. It is the value of tension that will cause the coil to have the lowest resistance possible. Any higher tension will cause more stretching of the wire and higher resistance.

When the resistance deviation curves are plotted with the minimum values at zero deviation, as shown on Figure 13, it will be noticed that the tension values at which the minimum resistance values occur, progress up the tension scale as the wire size increases. It will also be noticed that as the wire size increases the spread of the descending and ascendind portions of the curves increases. An increase or decrease in tension of ten grams will result in about one per cent increase in resistance for 41 gage wire, while for 35 gage, a change of 70 grams is needed. The spread of the two sides of the resistance deviation curve depends to some extent on how closely the wire is spaced on the coil; that is, the number of turns per inch or layer, and on the size of the coil in relation to the inside diameter. The curves on Figure 14 show the curves for (4) coil codes wound with 38 gage wire, and (2) coils wound with 35 gage wire having different I.D., number of layers and number of turns per layer.

If the values of tension that will give minimum resistance are plotted on semi-logarithmic paper, a straight line results, indicating that these values progress geometrically at a constant rate, the same as wire sizes do. See Figure 15. Also, if the tension values for increases of 1/2, 1, 2, and 3 per cent of nominal resistance are plotted, similarly straight lines result when the data from coils having similar dimensions are used.

ANALYSIS OF TENSION RESISTANCE RESULTS

The strength of wire and the amount of tension that can be used without stretching or breaking it is a function of the cross-sectional area of the wire. Since the wire gage sizes are developed by geometric progression, the relationships can best be studied with the information plotted on semi-logarithmic graph paper. This has been done on Figure 16 where the upper line shows the maximum tensile strength of 38,500 psi specified for this grade of wire. Also shown is a reference tension line at 15,000 psi, the level which had previously been used as a guide for setting tensions.

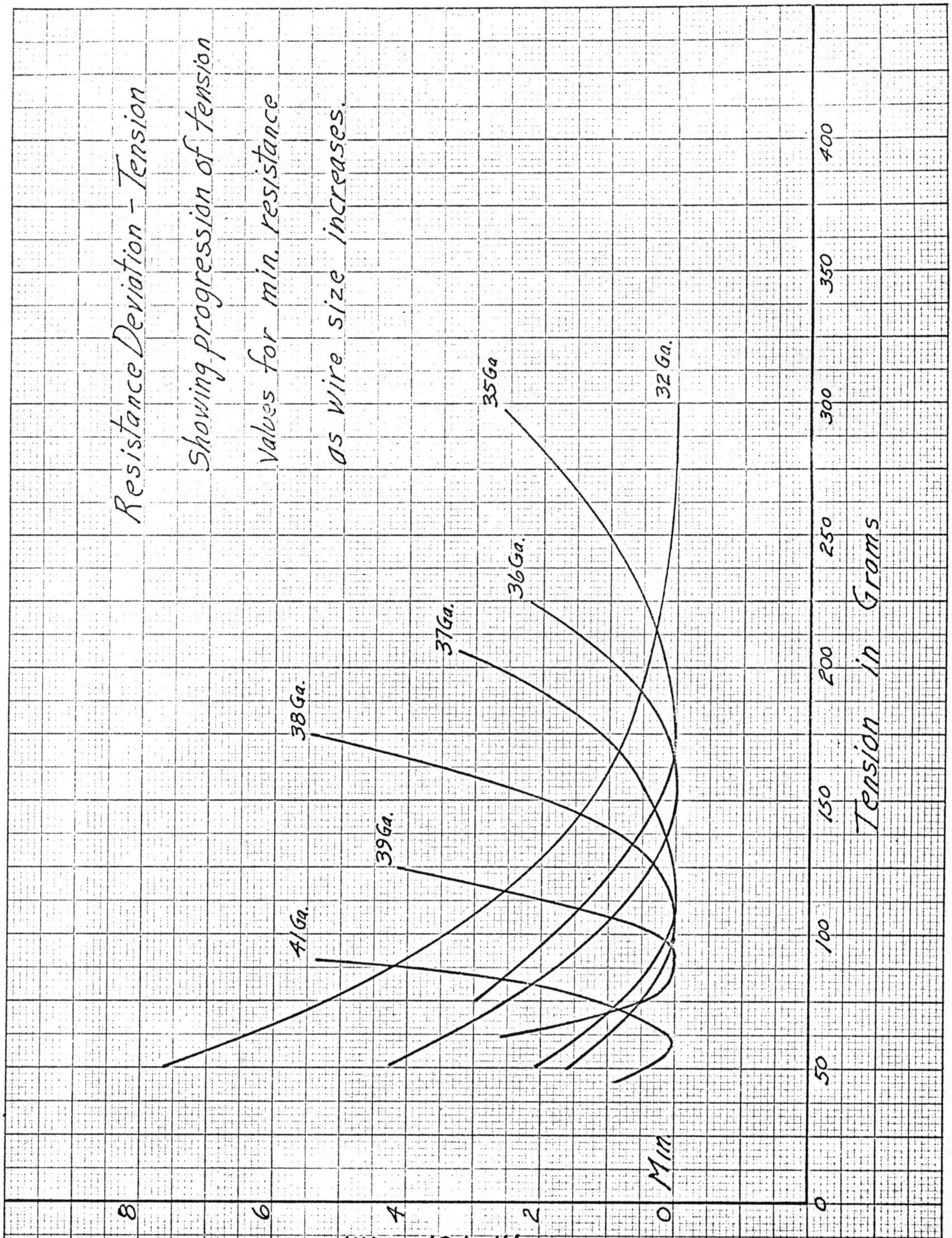
As a result of the studies made on the effect of tension on coil resistance and size, the tension values recommended in the last issue of the Omaha Wire Spring Relay Coil Winding Master Layout deviates somewhat from those on the 15,000 psi reference line. The Omaha values now are higher for small wire gages and lower for the larger sizes. They are the values, especially for the finer wires, that will give minimum average coil resistance because they are the minimum resultants of the two factors affecting coil resistance - that of a shorter wire being used because the coil is made smaller by using more tension, and that of the resistance increasing as the wire is stretched because of more tension.

It will be noticed that the line for the tensions recommended in the Omaha layout for the smaller gages 35-41 is not parallel to the maximum breaking load line or the 15,000 psi reference line, both of which are based on the wire cross-sectional area. It is interesting to note, but probably not significant, that it has a progression ratio of 1.19 which is almost exactly the average of the progression ratios of 1.123 and 1.261 mentioned earlier for wire diameter and cross-sectional area, respectively.

If points are selected on the coil resistance deviation tension curves where the wire starts to stretch, and these points are plotted as they are on Figure 16, we find that a line is formed that is parallel to the uniform psi lines, as one would expect. This line is equivalent to about 13,000 psi, indicating that this is the maximum strength of the wire to resist stretching. The tension values recommended in the Omaha Layout for gages 34-41 are above this line. Gages 38-41, for instance, are at the 17,100, 19,300, 20,600, and 21,400 psi levels respectively. Coils wound with these wire sizes at the layout recommended tension will have minimum resistance, but will have some wire stretchage. This tension is necessary to make the coils tight enough on the arbor to prevent slippage, to have coils that will not be oversize, and to have coils that will not have high resistance. For some coil codes, and under certain adverse wire conditions, it is sometimes necessary for the coil winding operator to use tension values slightly higher than those specified in the layout in order to produce coils small enough that they can be flattened sufficiently to meet the maximum coil thickness requirement. This must be done even though the coil resistance may run slightly higher because of increased wire stretchage.

At wire size No. 34, the tension line recommended by the Omaha Layout crosses the 15,000 psi reference line, and from there on through the larger wire sizes the tension increases progressively at a slower rate. This is because the lower values "iron" the cellulose acetate material down as far as it can go and there is little to be gained by using higher tensions. There are, however, many disadvantages of using higher tensions, including extra wear on the tensioning mechanism, coils hard to pull off the arbor, increased trouble with wire falling off the end of the coil, coils harder to flatten, trouble with collapsed coil centers, and coils difficult to assemble on cores in coil assembly.

The square points on Figure 16 are the highest tension values used in the tests. In some cases, the next higher step was tried but abandoned because of wire breakage, wire falling off the end of the coil, or the coil stick becoming too hard to pull from the arbor. The values at which most of the wires broke are marked with a triangle. Note how these points tend to be parallel to but slightly lower than the maximum breaking load line.



Resistance Deviation - Tension
Showing progression of tension
Values for min. resistance
as wire size increases.
Resistance Deviation from Minimum
in Per Cent
8
6
4
2
0
Min
0
50
100
150
200
250
300
350
400
Tension in Grams
41 Ga.
39 Ga.
38 Ga.
37 Ga.
36 Ga.
35 Ga
32 Ga.

Figure 13

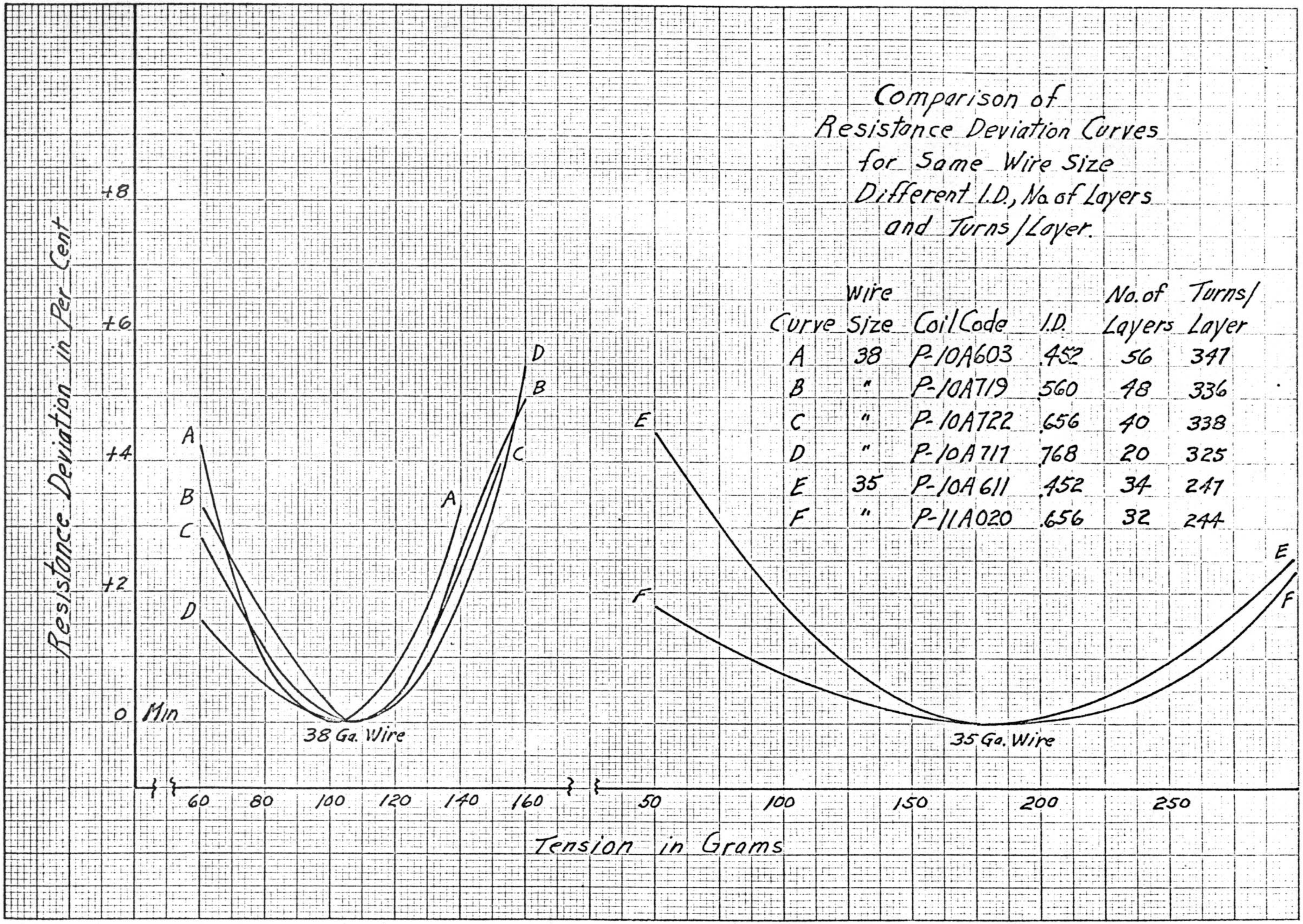
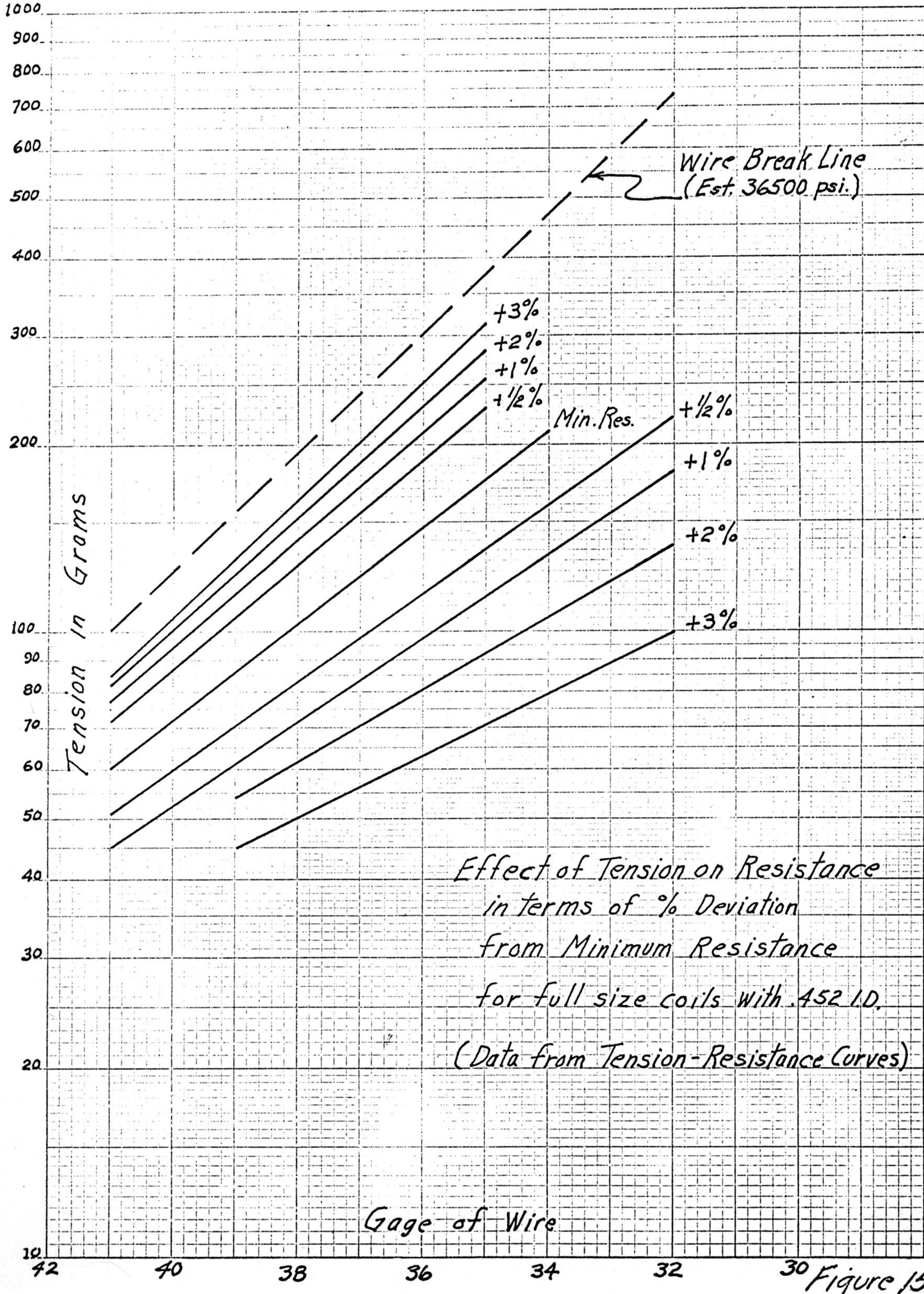

Comparison of
Resistance Deviation Curves
for Same Wire Size
Different I.D., No. of Layers
and Turns/Layer.
Curve | Wire Size | Coil Code | I.D. | No. of Layers | Turns/Layer
A | 38 | P-10A603 | .452 | 56 | 347
B | " | P-10A719 | .560 | 48 | 336
C | " | P-10A722 | .656 | 40 | 338
D | " | P-10A717 | .768 | 20 | 325
E | 35 | P-10A611 | .452 | 34 | 247
F | " | P-11A020 | .656 | 32 | 244
Resistance Deviation in Per Cent
+8
+6
+4
+2
0 Min
A
B
C
D
E
F
38 Ga. Wire
35 Ga. Wire
60
80
100
120
140
160
50
100
150
200
250
Tension in Grams

Figure 14



1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
Tension in Grams
Wire Break Line
(Est. 36500 psi.)
+3%
+2%
+1%
+½%
Min. Res.
+½%
+1%
+2%
+3%
Effect of Tension on Resistance
in terms of % Deviation
from Minimum Resistance
for full size coils with .452 I.D.
(Data from Tension-Resistance Curves)
Gage of Wire
42
40
38
36
34
32
30

Figure 15

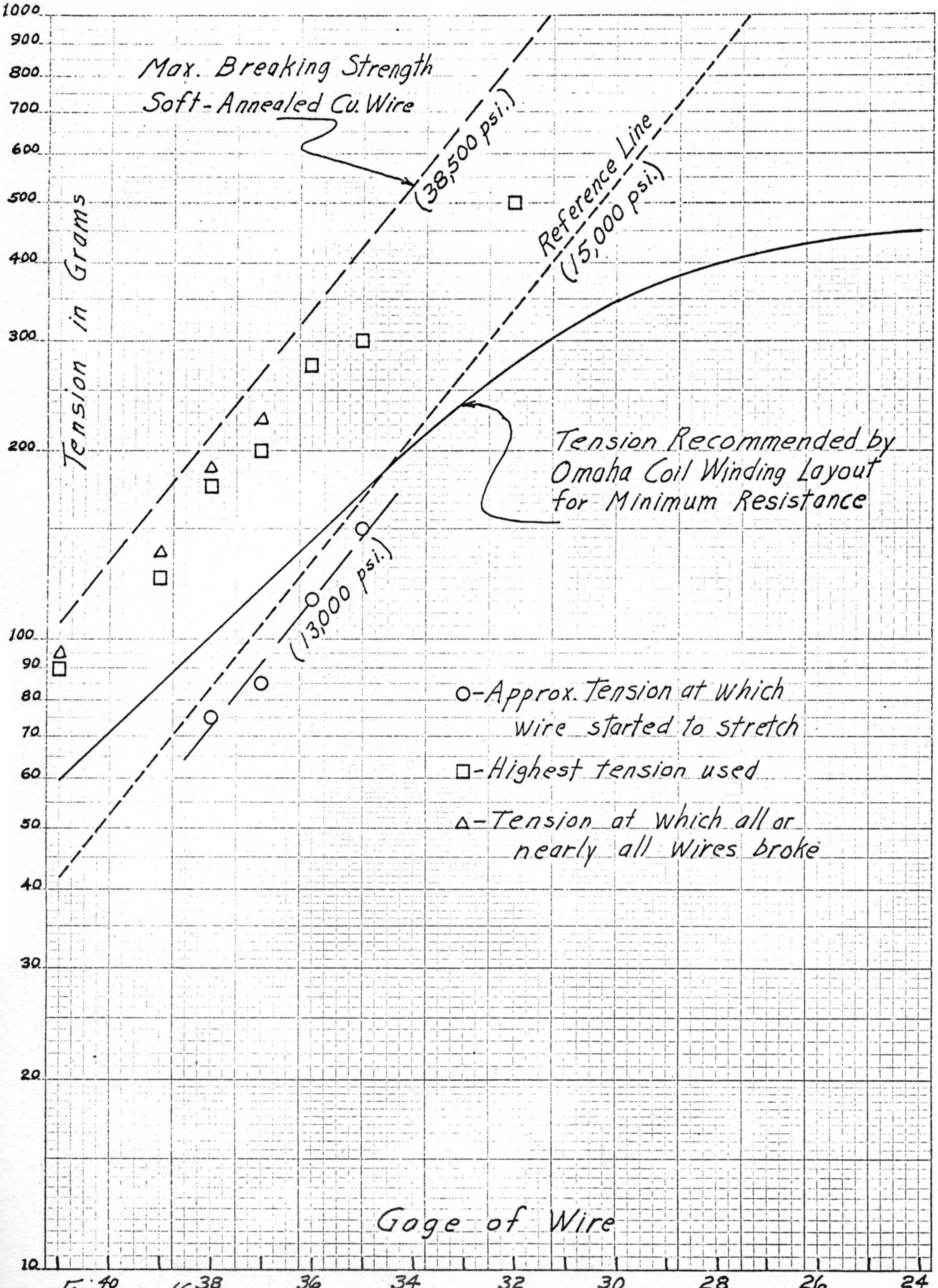

1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
Max. Breaking Strength
Soft-Annealed Cu. Wire
(38,500 psi.)
Reference Line
(15,000 psi.)
(13,000 psi.)
Tension in Grams
Tension Recommended by
Omaha Coil Winding Layout
for Minimum Resistance
○-Approx. Tension at which
wire started to stretch
□-Highest tension used
△-Tension at which all or
nearly all wires broke
Gage of Wire
40
38
36
34
32
30
28
26
24

Figure 16

MECHANICAL STRESSES DURING FLATTENING OPERATION

When a coil which has been wound on a round arbor is flattened to fit on a rectangular core, each turn of wire must be reshaped; part of each turn must be straightened and part must be bent to a shorter radius. On Figure 17, it will be noted that the portion between A and A' will be straightened. When this is done, the outer turns of wire will be under a force which will tend to shorten them; that is, they will be under compression. The inner turns will be under a force in the opposite direction and will tend to be stretched. As can be seen from the stress diagram, the amount of these forces is different for each layer of wire. The tensional force is greatest for the first layer of wire and diminishes for each layer outward until it reaches zero at about the middle layer. At this point, the forces of compression start to build up until they reach a maximum value at the last or outermost layer.

The portion of the coil between B and B' is made more curved when the coil is flattened and the forces resulting from this are set up in the opposite direction. The outer turns are under tension and the inner turns are under compression. The force diagram for B-B' is similar to that for A-A' except, of course, the forces are in the opposite directions. Between the A-A' and B-B' sections is an equalization area. The compression of the outer layers between A-A' and the tension of the outer layers between B-B' will tend to cancel each other. Likewise, the tension of the inner layers between A-A' and the inner layers between B-B' will tend to equalize.

At this point, the question might be asked, "what effect does flattening have on coil resistance, wire breakage, cross-sectional area of the coil and inner diameter dimensions?" The answer depends to a great extent on whether or not the coil had been wound with excessive tension; that is, whether the tension used was low enough to be absorbed by the cellulose acetate interlayer paper as it was formed in the grooves left by the previous layers of wire, or whether surplus tension remained in each turn of wire to accumulate turn-by-turn and layer-by-layer to form an inward force that was excessive.

The mechanical action of the flattening operation gives any force in the coil a chance to equalize. In effect, it tends to stress anneal the coil winding. If the forces are high enough, they will force material to move, to give way, until at least partial equilibrium is reached. If excessive winding tension had been used, it can be expected that the resulting high inward forces will force the coil to become smaller. The hole in the coil may become too small to permit easy assembly on the core.

The curve on Figure 18, showing the thickness of a coil after flattening, illustrates this point. The coil thickness decreased with increased tension at a decreasing rate until at about 80 - 85 grams tension there was no further decrease - the material had been "ironed" down and compressed as far as it could go. At 90 grams the coil thickness dropped decisively. The inner turns collapsed under the load and the hole became smaller, so much so that half of the coils wound at that tension could not be assembled on a core. A similar effect took place for the coil shown on Figure 19, except the collapse occurred at the higher tension of 150 grams.

If moderate winding tension is used so that there is no undue pressure toward the center of the coil, very little difficulty will be encountered. No wire breakage should result, the coil resistance can be expected to stay the same, and the coil center is not likely to collapse.

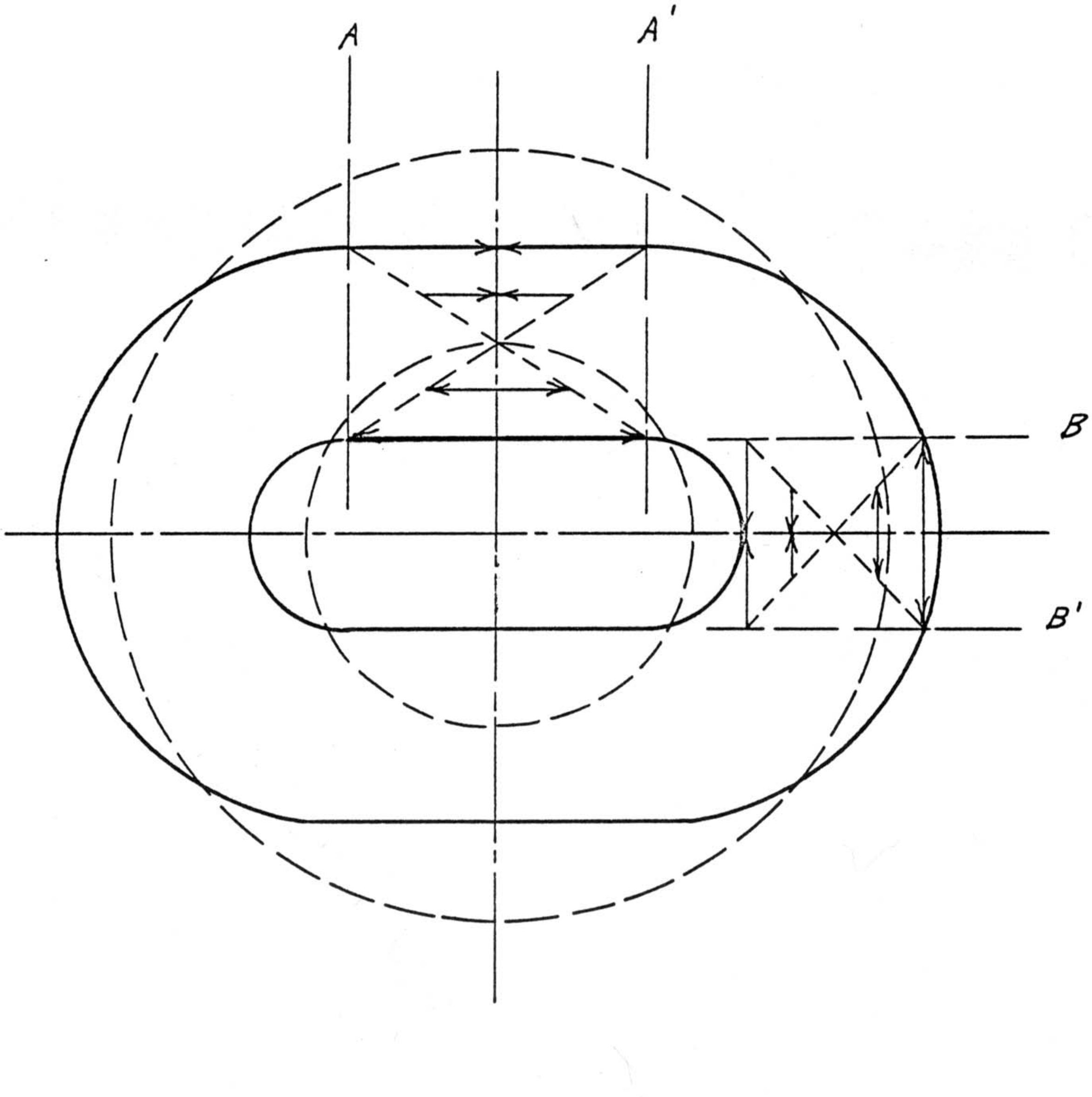
EFFECT OF TENSION ON ASSEMBLY OPERATIONS AND DROPOUTS

Some of the coil assembly operations are affected by coil winding tension, but usually only when the coil has been wound with excessive tension. If the core insulator has collapsed, as it does in many cases when high tension values are used, the operation of placing the coil on the coalescing tip is made more difficult because of the reduced effective size of the hole in the coil. For the same reason, the upper tip will not enter the hole as easily as it would otherwise, and many times the coil will be damaged beyond repair.

The simple operation of assembling the coil on the core is made more difficult, and sometimes impossible by excessive tension. The force built up turn-by-turn and layer-by-layer causes the coil hole to become smaller because tension higher than that which could be absorbed either by the cellulose acetate giving way or the wire stretching had been used. The result is that force must be used to push the coil on the core. This force may cause the core insulator to be pushed out of the coil, in which case the coil may have to be scrapped. In some cases, the coil may go on the core only part way. In a few such cases, it has been found that the coil could not then be removed from the core. Apparently, the forces in the coil caused the coil to collapse even more as it was being assembled to the core.

The tightness of the coil on the core has been known to be the cause of a few cases of inadequate bonding. The springs normally used in the bonding fixture for pressing the coil against the spoolhead could not force the coil to slide close enough to the spoolhead to permit the required amount of areas to become bonded.

There is good reason to suspect that some of the open coils that occur may be caused by excessive winding tension. A weak spot in the wire may survive the high winding tension long enough to become wound in the coil but fail later. If this failure occurs before final test, the open coil condition would be detected by the testing operation and the coil scrapped. Unfortunately, if a weak spot survived the assembly and testing operations, there would still be a chance that the excess tension would cause the wire to fail later and an open condition might occur in service.



Stress – Strain Diagram
for forces in Coil
During Flattening Operation

Figure - 17

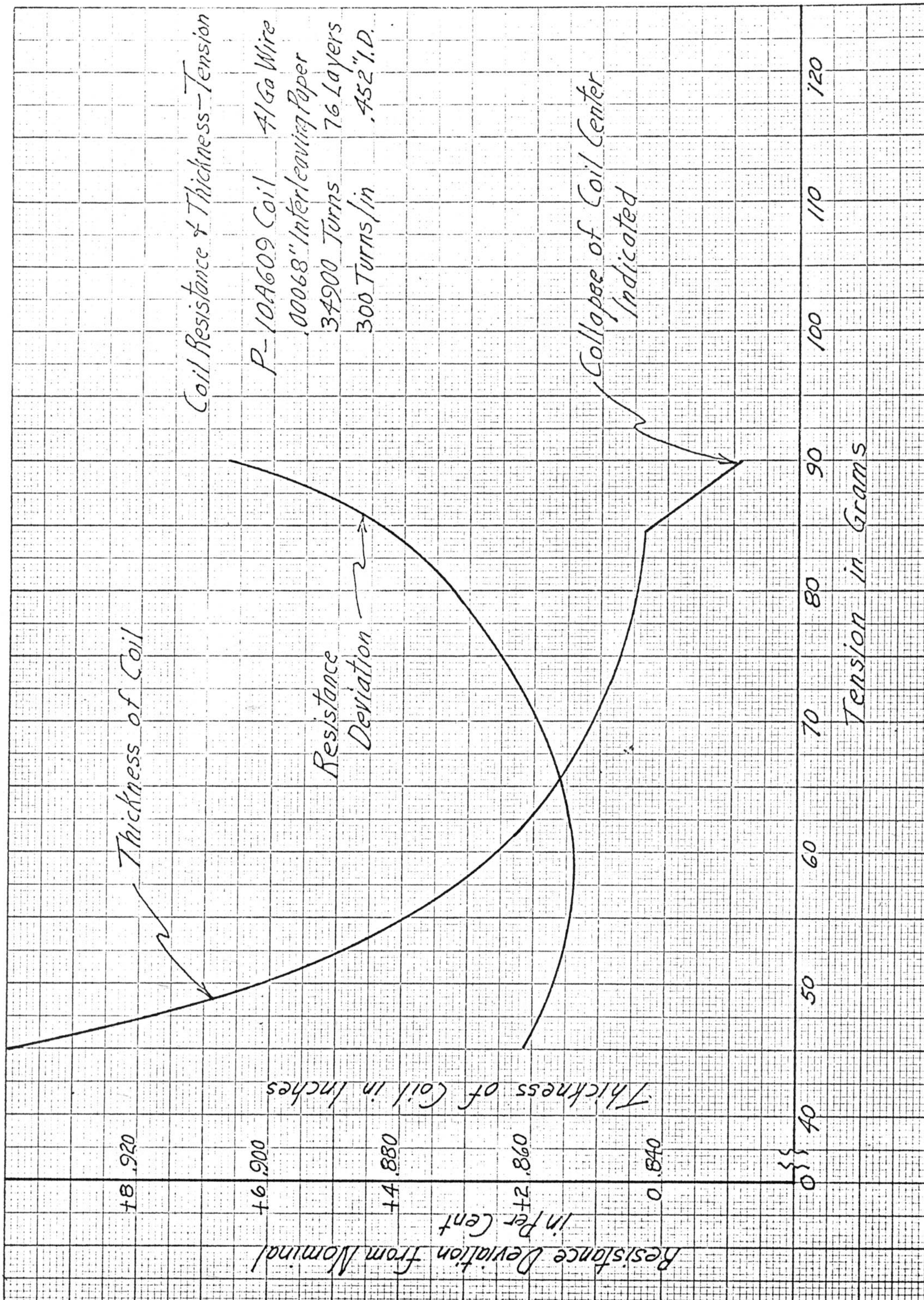

Coil Resistance & Thickness-Tension
P-10A609 Coil 41 Ga Wire
.00068" Interleaving Paper
34900 Turns 76 Layers
300 Turns/in .452" I.D.
Collapse of Coil Center Indicated
Thickness of Coil
Resistance Deviation
Thickness of Coil in Inches
Resistance Deviation from Nominal in Per Cent
Tension in Grams
+8 .920
+6 .900
+4 .880
+2 .860
0 .840
0
40
50
60
70
80
90
100
110
120

 Figure 18

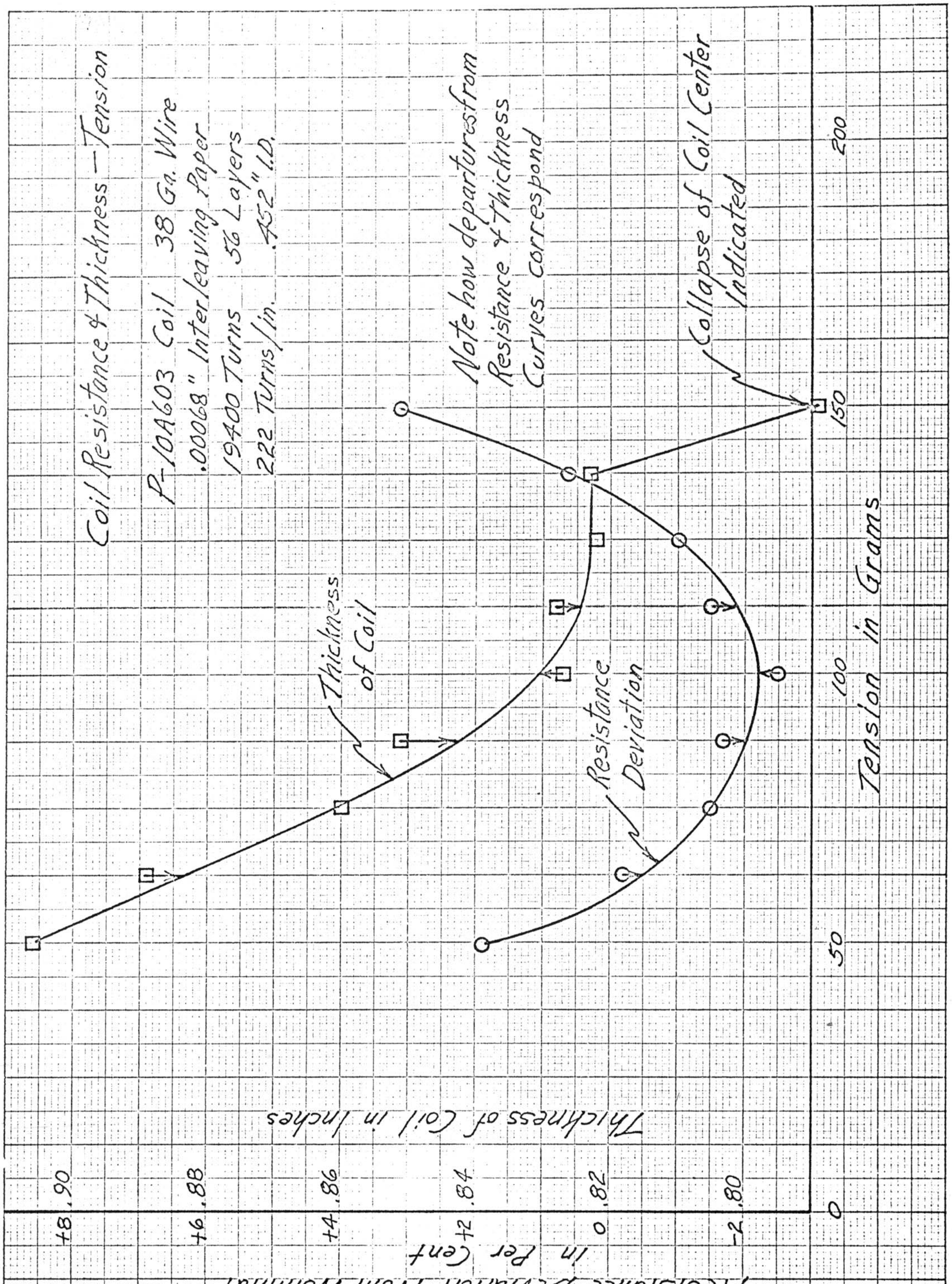

Coil Resistance & Thickness — Tension
P-10A603 Coil 38 Ga. Wire
.00068" Interleaving Paper
19400 Turns 56 Layers
222 Turns/In. .452" I.D.
Note how departures from Resistance & Thickness Curves correspond
Collapse of Coil Center Indicated
Thickness of Coil
Resistance Deviation
Tension in Grams
0
50
100
150
200
Thickness of Coil in Inches
.90
.88
.86
.84
.82
.80
Resistance Deviation from Nominal in Per Cent
+8
+6
+4
+2
0
-2

Figure 19

RECOMMENDATIONS AND SUMMARY

A good general rule to follow regarding coil winding tension is to use only as much tension as is necessary to make a good coil. Usually, this means a coil with near nominal resistance and a diameter small enough to be safely below any maximum size limit. If the coil is too large, it may be necessary to use more tension to reduce the coil diameter even though the wire may be stretched slightly and the resistance increased. This is assuming that the higher tension will actually reduce the size of the coil. If the cellulose acetate interleaving paper has already been "ironed down" as far as it can go, there is little hope of decreasing the coil diameter further, and more tension can only lead to difficulties inherent with too much tension. The most common of these are listed below:

1. Turns of wire tend to fall off coil into end margin.
2. Excessive wire breakage during winding can be expected.
3. Unnecessary wear of tensioning mechanism will occur.
4. The coil stick may be very difficult to pull from the arbor.
5. The coil resistance may be unnecessarily high because of wire stretchage.
6. More effort and care is required during flattening operations.
7. Coil center may collapse when coil is flattened, making coalescing operation more difficult.
8. Force may be required to assemble coil on core.
9. Some poor bonding may result.
10. Fine wire coils may become open-winding type defects.

Considerably fewer difficulties result from not enough tension. With extremely low tension, the coil stick may slip on the arbor unless taped in place. The coils will tend to be large and spongy and are very likely to have high resistance, because too much wire is used.

Tension can be thought of as a tool with which to make the kind of coil needed. As with any tool, it is important to understand it, to know what it can do, and what its limitations are, and then, to use it properly. The amount of tension and the results are definitely related. They have "rhyme or reason," and with the present means of measuring tension, there need be no guess work.

It is hoped that the information in this report will help others understand the effects of tension, and that it will serve as a guide for determining optimum tension values. It is also hoped that it will stimulate further studies of coil winding tension and that the information ultimately will result in coils being designed more nearly in agreement with practical coil winding and assembly factors.

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Omaha Works